ECHO SOUNDING

WITH SPECIAL REFERENCE
TO
MARINE SURVEYING

BY

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This pamphlet is produced by kind permission of Rear-Admiral J. A. EDGELL, O.B.E., *Hydrographer of the Navy, and consists of a reprint of articles written by Captain* P. S. E. MAXWELL, R.N., *of the Hydrographic Department, which originally appeared in the* Empire Survey Review *for July and October 1935 and January 1936.*

PART I

IN view of the fact that echo sounding is closely allied to sound ranging, the description of a purely maritime machine may be of some interest to shore-going surveyors, especially to those with military experience. It is proposed to give here a short history of echo sounding in a series of three articles, the first of which deals with models making use of the sonic system from the earliest form up to the perfected mechanism now in use; the second article will explain the principles of the super-sonic system and of the recording gear, while in the third it is hoped to give a general résumé of the results obtained and of the position at the present moment.

From the earliest days it has been realized that some form of depth measurement is necessary to the art of navigation, and until a few years ago very little change had been made in the methods employed. In the fifth century B.C. Herodotus in his famous description of Egypt remarked (ii. 5): "On approaching it by sea, when you are still a day's sail from the land, if you let down a sounding-line [*καταπειρητηρίην*, from *κατά*, down, and *πειράω*, make trial of] you will bring up mud and find yourself in eleven fathoms' water" (Rawlinson's translation). Five centuries later, in a vivid account of the storm encountered by St. Paul and his shipmates after leaving Crete and before being wrecked upon Malta, the author of "The Acts of the Apostles" wrote (xxvii. 27, 28): "But when the fourteenth night was come, as we were driven up and down in Adria, about midnight the shipmen deemed that they drew near to some country; and sounded [*βολίσαντες*, from *βολίς*, anything thrown], and found it twenty fathoms, and when they had gone a little further, they sounded again, and found it fifteen fathoms." These passages have a very modern ring about them, and it is evident that the operation on each occasion consisted of nothing else but heaving the lead, and this can have varied little in form through the ages right down to the present day.

During the latter half of the last century Sir William Thomson, afterwards Lord Kelvin, perfected a sounding apparatus based upon

an entirely new principle, involving a pressure tube which, lowered into the water, would register the depth reached and could afterwards be read by means of a suitable scale. This method was adequate for general navigational purposes but was not sufficiently accurate for the purposes of the hydrographic surveyor, who continued to use the "lead line" till the advent of echo sounding, though, of course, improvements had been made, such as the substitution of wire for hemp and the adoption of mechanical methods in lieu of the primitive and laborious means of heaving the lead, to which the earliest reference in English literature apparently dates from 1440 [see *O.E.D.* under "lead"].

Origin of Echo Sounding.—The following description of the origin of echo sounding is taken from an article by Per Collinder, lately published in the international *Hydrographic Review* (xi. 2, 63–9), being a translation of an extract from the *Svensk Geografisk Årsbok*, 1933, *pp.* 111–38. Actually the earliest record of echo sounding known to the present writer was recently given publicity by a letter in *The Times* of 11th October, 1934, where it is stated about M. Sacharof, who made a balloon ascent with Mr. Robertson from St. Petersburg in the year 1804, that: "The aeronaut ascended at a quarter past 7 p.m. At about half past 9 p.m., M. Sacharof directed his speaking trumpet to the earth and called as loudly as his voice permitted. His words returned in distinct echo after a lapse of 10 seconds, so that, reckoning from the velocity of sound, M. Sacharof concluded that they were about 5,700 feet from the earth."

"A hundred or 150 years before Lord Kelvin, seamen had already decided that the depth of about 100 fathoms roughly marked one of the most important nautical and geophysical limits, namely the limit between the continent and the ocean. Sounding was troublesome at greater depths owing to the facts that it became harder and harder to detect the instant when the lead touched the bottom, that it was not easy to keep the ship sufficiently stationary, and furthermore that the bottom generally starts to drop sharply towards the depths from beyond this limit. Here begins the 'blue water' of the great sailing ships, beyond which it was only possible to navigate by means of the compass and the stars, until they reached the 100 fathom line which is the beginning of the region they called 'the soundings', known by modern oceanographers as 'the shelf'. The deep blue water was said to be unfathomable, but it happened at the beginning and in the middle of the XIX century that some hardy explorers tried to sound the oceans. Thus in 1852 H.M.S. *Herald*, Captain Denham, took a sounding of 7,660 fathoms in lat. 36° 49′ S., long. 37° 6′ W., where recent soundings have only given 2,734 fathoms. The discrepancy is due, without a doubt, to a failure to observe the exact instant when the lead touched the bottom, owing to the line continuing to run out under the action of horizontal currents. A pioneer in this domain was Matthew Fontaine Maury, the founder of oceanography and marine meteorology. With his collaborators he developed

accurate methods, towards 1850, by means of which it has been possible to verify that the greatest depths of the Atlantic Ocean are, in general, between 2,700 and 3,300 fathoms.

"In the latter half of the XIX century the general depth of the Atlantic Ocean was fairly well known, as was that of certain parts of the other oceans. This was chiefly a result of the efforts necessary for the laying of the great telegraph cables; without this, our knowledge of the great oceanic depths would have remained even more precarious.

"An ocean sounding at a depth of 2,500 fathoms or more has always been an undertaking and in bad weather needs a particularly well-trained crew to perform successfully. Sometimes also the operation requires long hours, and it is not at all surprising in these conditions that at the beginning of the XIX century well-informed oceanographers gave much attention to finding new aids for the purpose and were inspired, it appears, by the fortunate measurements of depth in the stellar system with which the 'organist of Bath', Sir William Herschell, laid the foundation of stellar astronomy.

"According to the most trustworthy information in our possession, it seems to have been Jean-François Arago, whose active genius pervaded the most varied realms of human activity and who was a great friend to the French hydrographic engineers, who in 1807 suggested the use of sound for measuring great depths. The time was not yet ripe; it was only towards the middle of the XIX century that Maury took up the question anew. In his book, 'The Physical Geography of the Sea and its Meteorology', which went into some twenty editions and which can still be recommended to any geographer interested in the sea, he recounts his unsuccessful attempt as follows:

'By exploding petards or ringing bells in the deep sea, when the winds were hushed and all was still, the echo or reverberation from the bottom might, it was held, be heard, and the depth determined from the rate at which sound travels through water. But, though the concussion took place many feet below the surface, echo was silent, and no answer was received from the bottom. Ericsson and others constructed deep-sea leads having a column of air in them, which, by compression, would show the aqueous pressure. . . . Mr. Baur, an ingenious mechanician, constructed . . . a small piece of clockwork for registering the revolutions made by a small propeller during the descent. . . . An old sea-captain proposed a torpedo. . . . One gentleman proposed to use the magnetic telegraph. . . .'

"All these attempts failed, but while the question of the geography of the ocean floor was in a fair way to being solved by the use and improvement of the early methods of line sounding, the decade of the Great War saw the technical realisation of the sonic sounding suggested by Arago and Maury.

"It is always a delicate matter to make statements on matters of priority, but it seems hardly possible at present to deny that modern sonic sounding was made a practical possibility by the Austro-German

physicist, Dr. Alexander Behm, at Kiel. Dr. Behm's investigations in this domain started after the foundering of the *Titanic* on 14th April 1912 as the result of collision with an iceberg. This disaster, which made a great impression in the world, raised the question of assuring communications on the most frequented traffic lanes between Europe and the north of North America against the risks to which the liners are exposed from icebergs coming down from Greenland. . . .

"If the attempts to determine the approach of an iceberg by means of the submarine echo have failed, they have at least led to the discovery of the acoustic measurement of depths. When in 1912 Dr. Behm undertook research in this direction, it was not yet known with certainty whether such a thing existed as an echo in water. The reason for this ignorance was very likely due to the fact that over short distances the echo returned too fast to be distinguished from the original sound. It is in this peculiarity that the greatest difficulty resides which remains to be conquered in the method of sounding by echo.

"In order to be able to study the translation of sound in water, Dr. Behm emitted sound in an aquarium, in which he succeeded in photographing the sound waves. He found a well-marked reflection, both from the bottom and sides of the receiver and from the free surface of the water, and even from a much-bent metal foil. The size of the aquarium was roughly $11 \times 10 \times 5$ ins., and if we compare these dimensions with the velocity of sound in water (about 4,900 ft. per second), we shall realise the difficulties of the problem Dr. Behm had to solve. He succeeded in making visible waves which followed each other in the water at an interval of time of 1·5 millionths of a second, and conceived an apparatus for measuring time to this degree of precision."

Principles of Echo Sounding.—Having thus learnt the origin of echo sounding we will proceed to investigate a few brief descriptions of the different ways in which acoustic echoes can be used for the measurement of the depth of water beneath a vessel. The elementary principles are so well known to the readers of this article that it appears unnecessary to enunciate them, as it is obvious that if v is the velocity of sound in sea-water and t the interval of time between the emission of an impulse and the reception of its echo, then it follows that the depth of water is $\frac{1}{2} vt$; there are, of course, various corrections which may have to be taken into account, but those will be dealt with later. Many kinds of apparatus have been tried, different nations working on different lines; but in nearly all cases, since the depth is directly related to the time-interval, the instrument is graduated to read depth direct. In all types the procedure is roughly the same, *i.e.* the emission of a sound signal, the electrically recorded time-interval for its returning echo and the final translation of time into depth.

From a single source of sound the angle of spread of the sound waves emitted is determined by the relation between the wave-length

and the dimension of the source; by using short waves it is possible to bring the relation between the diameter of the aperture at the source and the wave-length to such proportion that a beam of sound is produced. This is the fundamental difference between directional and non-directional sound waves as used in echo sounding, and all the different types of echo sounders in use to-day can be thus classified as directional or non-directional. As directional waves are of high frequency and inaudible, they are called supersonic, while non-directional sound waves are of low frequency and being audible are known as sonic. Briefly, the history of echo sounding has proceeded simultaneously in both types. The French or Langevin system has been entirely directional or supersonic; the American and German have been entirely non-directional or sonic. The British Admiralty have experimented with both, although up to recent date the sonic or non-directional has been principally employed, and it is with this type that this first article is concerned. It is not easy to draw a comparison between the two, as excellent results have been achieved by all the different types; but as a result of seven years of intense work it may be said that certain definite features have been evolved which will be incorporated in all echo sounders in the future. The main objection to both types in earlier days was, that it was impossible to obtain accurate soundings in very shallow water, not owing to want of accuracy in the receiving apparatus but to the nature of the *sound-producing* apparatus, whether sonic or supersonic. Although it can be said that the very shallow depths are not important, the fact that ships fitted with echo sounders can still go ashore is regarded by the Board of Trade and all competent authorities as revealing a distinct defect in the apparatus.

Since both the transmitter and receiver are immersed in the same medium, it is obvious that the receiver will respond directly to all impulses sent out by the transmitter, if they are placed too close together. In order to obviate this trouble, much care must be taken in making a suitable choice of the relative positions of the transmitter and receiver in order to lessen the direct impulse when transmitted through the water from one to the other. This distance apart is usually known as the "separation" and varies with different ships; and it is obvious that the shoaler the water, the more obtuse is the angle made between the paths of the impulse proceeding from transmitter to sea-bed and from sea-bed to receiver, and the larger the error in the vertical distance below the ship's bottom. Within limits this error can be corrected by mechanical means, but in very shallow depths the correction becomes so great as to give erroneous results. Further reference will be made to this in Part II.

*Admiralty-pattern Echo-sounding Gear, Sonic Type.**—Reference has been made above to Admiralty experiments with echo-sounding gear, so now it is proposed to give a short description of the standard type; but here a few general remarks must be interpolated. Although echo sounding appears at first sight to be an easy method

* Manufactured by Messrs. Henry Hughes & Son, Ltd., 59 Fenchurch Street, E.C.3.

of getting over navigational difficulties, there are several troubles met with in its practical use. The position in which the transmitter and receiver are placed in the ship is of great importance, as a position free from vibration and if possible at the centre or flattest part of the ship must be chosen. The echo sounder was not catered for in the original design of the ship, and frequently a position has to be accepted which is not necessarily the most suitable. For instance, any projection, such as bilge keels or bottom log, will cause aeration, *i.e.* bubbles of air passing over the bottom of the ship, which has a very bad effect on echo sounding, since both receiver and transmitter are very susceptible to and easily influenced by air bubbles. A case in point is that of the bow wave passing under the ship and forming a cloud of air bubbles, thus upsetting the continuity of the medium through which the sound waves are passing. A bad reflecting surface, such as a steep slope, rock in slab formation, mud or silt in river mouths, even sand grains moving under the influence of tide, will tend to destroy or weaken the echo.

In measuring depth of water by echo methods a ship emits an underwater sound impulse which travels outward through the sea at an approximately uniform speed. On reaching the ocean bed part of the sound impulse is reflected and returns to the ship in the form of an echo, where its arrival is indicated by some form of measuring apparatus. The velocity of sound in its passage to and from the ocean bed is known, so that by measuring the time-interval between making the sound and the return of the echo an observer on the ship can determine the depth of water, and it is for this that the Admiralty-pattern sonic echo sounder has been evolved. It may be noted that in shallow water this time-interval is extremely short; the time taken for a sound impulse to travel to a depth of 10 fathoms, to be reflected and to return to the ship, is about 1/40 second.

Description of Machine.—The principal parts of the Admiralty sonic echo-sounding gear are:

1. *Transmitter*, which produces the sound;
2. *Hydrophone*, which picks up the echo;
3. *Receiver*, which contains the time-measuring device for reading the depth of water.

The sound impulse in the sonic system is produced by a blow from a spring-driven electro-magnetically operated hammer on a steel diaphragm which is in contact with water in a tank secured to the ship's hull; the sound impulse is transmitted through the water to the hull of the ship which acts as a diaphragm and retransmits the impulse to the sea outside the hull. The echo from the bottom is received in a hydrophone, secured to a tank in the same manner as the transmitter and consisting of a microphone and diaphragm which are set into vibration by the echo.

A $\frac{1}{8}$th-horse-power motor, running at 1,800 revolutions per minute, drives two switches through a ten-to-one reduction gear. These switches consist of brushes bearing on a rotating disc with insulated segments. One of them breaks the circuit to the solenoid of the

DIAGRAM A

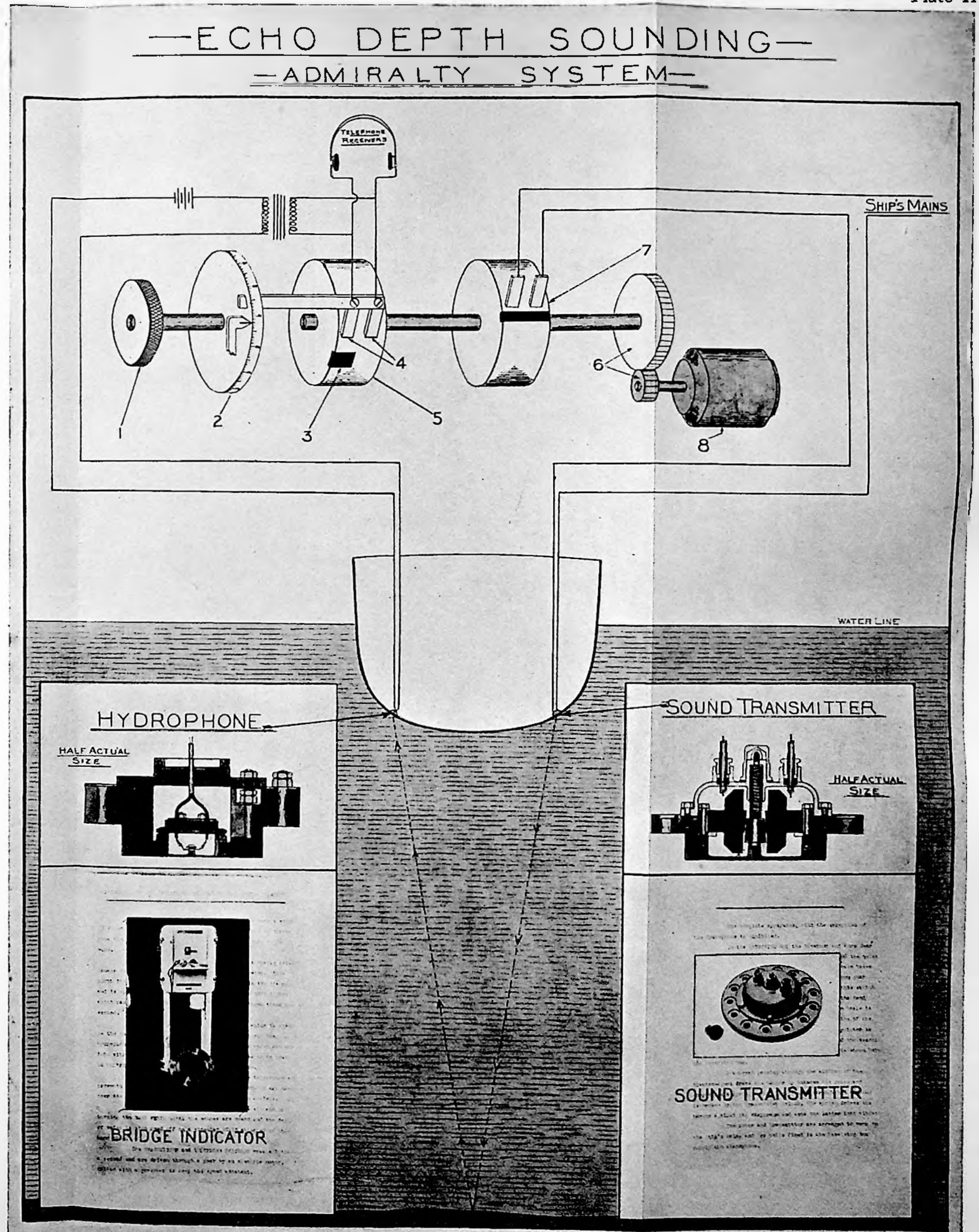
[NOTE : *The words* HALF ACTUAL SIZE *in the diagram do not apply*]

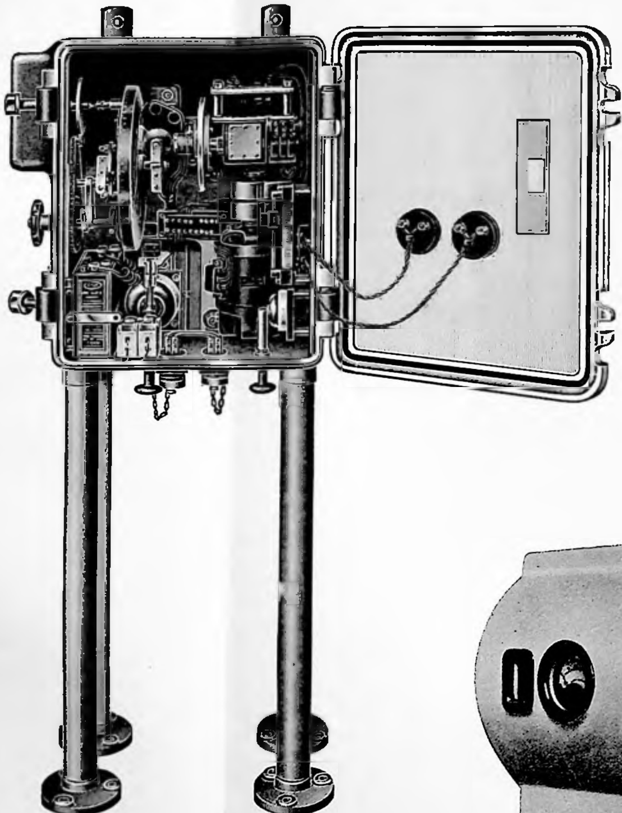
This semi-diagrammatic illustration is taken from a block kindly lent by Messrs. Henry Hughes & Son, Ltd., the manufacturers of the Admiralty-pattern Echo-sounding Gear, and gives a general outline of the arrangement of the gear.

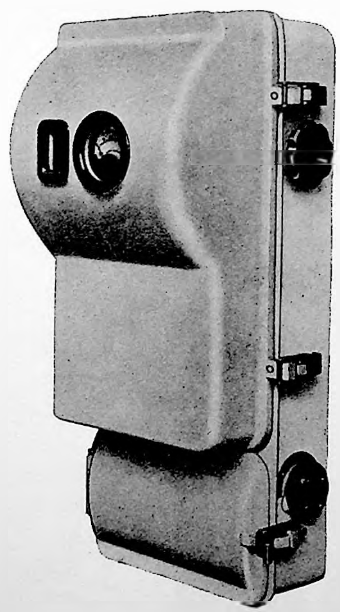
Reference numbers in the upper section:

1. The handle controlling the movement of the depth scale.
2. The depth scale, divided in fathoms and representing the time-interval between the original impulse and the return of the echo.
3. A small ebonite circuit-breaker on the telephone switch drum.
4. The two brushes in the receiving circuit which maintain the telephone receivers shorted, except when open for the short period represented by passing over the ebonite segment at 3.
5. The telephone switch drum.
6. The gear connecting the motor and shaft for rotating the telephone switch drum.
7. The transmitter switch drum connecting up to the ship's mains.
8. The constant speed motor.

Following the leads down into the diagrammatic hull of the ship we see that they connect on the one side to the transmitter and on the other to the hydrophone, small photographic reproductions of which are shown. The left-hand bottom photograph shows the apparatus as it appears on the bridge, the wheel shown above as 1 is on the left of the box, while the depth scale 2 can just be seen in small window in the middle of the front of the box.







DIAGRAMS B AND C

These photographic reproductions, kindly lent by Messrs. Henry Hughes & Son, Ltd., the manufacturers of the Admiralty-pattern Echo-sounding Gear, give a representation of the receiving gear as mounted on the bridge, both open and shut. The handle controlling the movement of the depth scale and the depth scale itself are clearly visible.

DIAGRAMS B AND C

These photographic reproductions, kindly lent by Messrs. Henry Hughes & Son, Ltd., the manufacturers of the Admiralty-pattern Echo-sounding Gear, give a representation of the receiving gear as mounted on the bridge, both open and shut. The handle controlling the movement of the depth scale and the depth scale itself are clearly visible.

transmitter three times a second for about 0·0025 second, whilst the other, running on the same shaft, short circuits the telephone in the receiving circuit, unless the circuiting is controlled by the position, relative to the corresponding pair of brushes, of a second insulating segment. This latter pair of brushes can be displaced by a hand-wheel and, if a sound is heard in the telephone, the time taken for the insulated segment of the disc to travel the amount of the displacement must be the same as that taken by the transmitted sound to travel to the bottom and back to the receiver. The velocity of sound in water and of the revolution of the switches being known, it is possible to graduate this displacement of the brushes in terms of the depth in fathoms, and this is done on a circular scale on the hand-wheel. It is clear that the speed of the motor is all-important, and a specially designed centrifugal governor controls it to a constancy of 1 per cent. despite variations in the supply voltage.

The above brief description is very rough, as it is not the purpose of this article to give a technical explanation, but the actual gear is not nearly so complicated as it sounds and can be kept in running order by any qualified electrician. This sonic gear, which has now developed into what is known as type 752, has been in continual use in all H.M. surveying ships for some time past and also in a great many of H.M. ships of war. In fact, it has recently been decided to fit one in almost every ship in the Navy.

Deep-water Soundings.—For navigational purposes an accuracy of one part in 300 is ample. Such soundings are nearly always taken on the continental shelf which in most parts of the world means inside the 100 fathom line. In such depths a vessel is not far from the land, and owing to the gentle and regular slopes a line of soundings gives the maximum of information. The depths are entered on the chart to the nearest fathom and, if they are correct to one in 300, any error will not affect the unit place. Outside the continental shelf lies the narrow steeper continental slope which dips from the edge of the shelf to the bottom of the ocean in one or two thousand fathoms. It is not likely that this will ever be sounded with great accuracy, and there is good reason to believe that it is so irregular and narrow that an error of one in thirty would not make much difference to the resulting fix. As for sounding in the deep sea, it is hardly likely that a ship would be so far uncertain of her position that a sounding on the long gentle slopes of the bottom would be of much assistance. An exception must be made in the case of cable laying, where a knowledge of the depth is of great importance in order that the cable may be paid out at the correct rate, and in the case of soundings made for scientific purposes, where a higher degree of accuracy, or perhaps relative accuracy, is desirable.

It is not possible to check an echo sounding in deep water by means of a wire sounding, since we do not know whether the wire is straight up and down. Good agreement has, however, been obtained between the observed horizontal velocity and the velocity calculated on theoretical grounds by means of the Admiralty "Tables of the velocity

of sound in pure water and sea water for use in echo sounding and sound ranging"; these Tables are derived from the properties of sea-water as determined in the laboratory and show the effects of the temperature and salinity of the sea at the time of the observation in modifying the velocity. In the Straits of Dover the difference varied from one in 700 under unfavourable conditions in the winter to less than one in 15,000 under favourable summer conditions. This last close agreement, though the result of averaging a number of experiments, is, of course, due to pure chance. There is no reason to suppose that the agreement would be very much worse in deeper water, and there is therefore every probability that the Tables are correct to one in 300 at all depths.

The method of computing the velocities is given in the Tables and there is no reason to repeat it here. It will be sufficient to extract some figures showing the effect of an error in the assumed temperature and salinity. At 0° C. and atmospheric pressure, an error of 1° C. would cause an error of 4·6 metres per second in the velocity; at 5° C. the error would be 4·1 metres per second, and at 30° C. 2·1 metres per second. These correspond to one in 314, one in 358, and one in 735 respectively. Great depths have little effect on these errors; at 8,000 metres the error in the velocity and therefore the sounding would be one in 289. With modern reversing thermometers an accuracy of a few hundredths of a degree is easily attained, and once the average vertical temperature-distribution has been determined there should not be any difficulty in reaching an accuracy of one in 300 in the depth. The effect of an error in the salinity is far less; it would have to be a very large error to cause an error of one in 3,000 in the sounding.

Part II. The Supersonic or Directional Type and the Chemical Recorder

In Part I an attempt was made to give a general description of the inchoation and development of echo-sounding systems as opposed to the older and time-established methods for obtaining the depth of the sea, found so necessary by navigators and hydrographers throughout the ages. At the time of its inception, a brief decade or so ago, the new invention was rightly considered to be epoch-making, but the present generation has acquired the habit of accepting all the latest miracles of science as a matter of course and consequently regards echo-sounding as an established fact; we must, therefore, look to newer and more spectacular developments to surprise the mid-twentieth-century mind.

The previous article traced the great change in methods which were so drastically altered after 2,500 years or more. It now remains to describe a new apparatus which, even if regarded as a logical development, might still appear to be of sufficiently arresting and spectacular a type to catch the mind of this up-to-date generation. From the mercurial barometer and surveyor's aneroid to the recording barograph, from the thermometer to the thermograph, from the stenographer to the dictagraph, are easy and obvious steps; but the change in system from the sonic to the supersonic and from headphones to a recorder that gives a continuous and accurate contour of the sea-bed is a development of far greater significance.

Before proceeding with a description of the new system, I should like to say that these notes are largely copied from a paper recently read at the Institution of Electrical Engineers, by whose kind permission I have been allowed to make extracts. The paper was entitled "A Magnetostriction Echo Depth-Recorder", by A. B. Wood, D.Sc., F. D. Smith, D.Sc., Associate Member, and J. A. McGeachy, B.Sc., who were immediately responsible for the introduction of the present gear. (See *J.I.E.E., vol. 76, pp.* 550–566.)

The High-Frequency or Supersonic System.—As stated in Part I of this article (*p.* 5), echo systems can be and have been conveniently divided into two main classes:

(*a*) Low-frequency or sonic system.

(*b*) High-frequency or supersonic system.

The former, the British Admiralty system, is of the low-frequency type and has already been described. Experiments with electro-chemical recorders adapted to this system have been made, but it was not until the introduction of the high-frequency or supersonic type

of gear that it became possible to evolve a practical unit as accurate in use in *shallow* water as it is in deep water.

The only high-frequency system which had hitherto attained commercial importance used the supersonic vibrations of a quartz piezo-electric oscillator. This system, devised by Prof. Langevin and M. Chilowsky, has been developed commercially in this country by the Marconi Sounding Device Company. The present article is, however, concerned with a description of an entirely new type of high-frequency echo depth-recorder which possesses important advantages over the two types mentioned above.

It is desirable to explain that this new system of echo-sounding was devised to meet a definite requirement which could not be met by any system then in existence (1930). This requirement involved the production of an echo depth-sounding apparatus to give a continuous record of the depth of water beneath a survey motor-boat of draught about 2 ft. travelling at full speed. A depth-range of 0 to 200 ft., with an accuracy of about 1 ft., was specified. The first attempts were made with a modified form of the Admiralty-pattern depth-sounder of the sonic type. The modified apparatus gave promise in a large tank at the Admiralty Research Laboratory but proved less satisfactory when tested at sea because of extraneous noises due to engine, propeller, and splashing water, which almost completely masked the relatively weak echo from the sea-bed. Furthermore, a serious practical difficulty arose in connexion with the screening of the receiver from the transmitter. This was due to the fact that the wave-length in water of the low-frequency sound was comparable with the dimensions and draught of the boat, an unduly large proportion of the emitted sound consequently reaching the receiver by diffraction. These difficulties are inherent in all low-frequency systems, and it was therefore considered preferable to avoid them by the use of a high-frequency system rather than to attempt to evolve expedients for overcoming them.

Description of the New System.—After experiments with various types of high-frequency sound sources suitable for use under water it was finally decided to employ a principle which had hitherto found little practical application, *viz.* magnetostriction. The detailed design and construction of high-frequency magnetostriction transmitters and receivers will receive attention later, but for the present only the general application to depth-sounding will be considered.

The general arrangement is illustrated diagrammatically in Fig. 1. Two magnetostriction oscillators, a transmitter and a receiver, are mounted side by side in water-filled tanks and fitted in a chosen position in the boat or ship. The transmitter is excited into resonant vibration at regular intervals of time, depending on the range of depth to be recorded. These sound-impulses are timed by means of suitable motor-driven contacts which synchronize with the traverses of the recording point across the record. The sound-impulse may be either a damped train of high-frequency oscillations or a short signal of constant amplitude obtained from a convenient source of alternat-

ing current. The short train of high-frequency sound-waves is directed vertically downwards to the sea-bed, whence it is reflected back to the magnetostriction receiver. Here the high-frequency pressure fluctuations are converted into corresponding alternating curr-

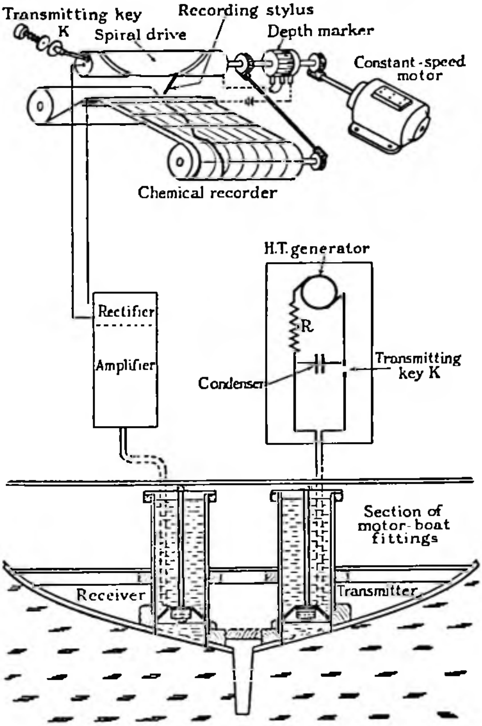


FIG. 1.—Magnetostriction echo depth-recorder. General arrangement.

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ents. These currents are amplified, rectified, and passed through the recorder. The latter is driven by the motor which controls the transmitting contacts, and the recording point is so arranged that its zero position on the record coincides with the instant of transmission of the sound-impulse. While the sound-impulse is travelling from the transmitter to the receiver via the sea-bed, the recording point has travelled a corresponding distance from left to right of the paper. Various types of recorder have been used, but a chemical recorder has hitherto proved most satisfactory, especially at the relatively

high speeds of recording required in very shallow water. In the chemical recorder a small electrical current produces a stain on a chemically treated paper. Two such stains are, in general, produced at each traverse of the recording point, the first at the instant of transmission (the zero) and the second on the arrival of the echo. As the paper is slowly fed forward in a direction at right angles to the traversing point, two stained bands are obtained, one of which represents the zero or sea-surface whilst the other represents the sea-bed. A continuous record is thus obtained of the contour of the sea-bed as the ship proceeds on its course. The width of the zero band is determined by the sound reaching the receiver either by diffraction or by transmission through the hull. This band is of appreciable width but less intense than the echo band in very shallow water. In order to record very shallow depths it is therefore sufficient to reduce the sensitivity of the amplifier. An auxiliary commutator is used to produce a depth-scale on the record, a series of equidistant dots representing known depth-intervals being recorded at each traverse of the recording point. As already stated, the apparatus was originally designed for recording depths from 0 to 200 ft., but the method has also proved satisfactory in depths exceeding 400 fathoms.

The Magnetostriction Oscillator—Transmitter and Receiver.—Some ferromagnetic materials possess the properties of changing their linear dimensions when subjected to a magnetic field (the Joule effect) and conversely of changing their magnetic condition when mechanically strained (the Villari effect). These properties have formed the subject of research by numerous investigators in a wide range of alloys, especially the alloys of iron, nickel, and cobalt.

The selection of a suitable material for a magnetostriction oscillator is to a large extent determined by considerations of a practical nature. A compromise between various conflicting factors is necessary; we must bear in mind that the oscillators must be reproducible in large numbers on a commercial scale. The material selected must possess as far as possible the following qualities:

(1) Large magnetostrictive effects for relatively small magnetic fields.

(2) Simple and easily reproducible composition. (Alloys requiring exact proportions and exceptional heat treatment are therefore unsuitable, unless they possess a large compensation in (1) above.)

(3) Good mechanical properties. The material must be available in thin sheet and stampings and in the form of thin-walled tubes.

(4) High resistance to corrosion when immersed for long periods in water.

Combining these desirable qualities, nickel of ordinary commercial purity appears to be the most suitable magnetostrictive material for the purpose; it is simple in composition and easy to anneal; it has good mechanical properties and can be readily obtained as thin sheets, tubes, or stampings; and it has a high resistance to corrosion, remaining for long periods in water without sign of deterioration. With regard to its magnetostrictive properties, nickel is, as we have

shown, one of the best materials obtainable. Nickel has been chosen on these grounds for the magnetostriction oscillators used with the Admiralty-pattern echo-sounding gear. Various alloys have been tried, but as yet the results have not proved so satisfactory, for one or more of the reasons given above. In what follows, therefore, we shall be concerned with nickel magnetostriction oscillators.

Design of Oscillators.—If a magnetized rod is subjected to the action of an alternating magnetic field parallel to its length, mechanical oscillations at the frequency of this alternating field are set up; when this frequency coincides with the natural frequency of the rod in longitudinal vibration, resonance occurs and a large increase in the amplitude of vibration results. Under these conditions of resonance the rod becomes more efficient as a source of sound. The phenomenon in this simple form is practically useless for the generation and reception of sound at high frequencies. In the first place, the eddy currents in the rod prevent the penetration of high-frequency alternating magnetic fluxes, and only a thin layer of the material on the outside of the rod is effective in producing vibrations. Again, the demagnetizing effect of the ends of short bars (of high longitudinal frequency) prevents the magnetic induction from attaining sufficiently high values. Consequently it is desirable that the magnetostrictive material should be constructed (*a*) of thin sheet or laminations, and (*b*) in the form of a closed magnetic circuit.

The first of these requirements appeared to present an almost insuperable difficulty. Thin laminae are not usually regarded as capable of resonant vibration at high frequencies. Experiments have shown, however, that such laminae, if not excessively thin, resonate reasonably well, the internal damping being small relative to that due to radiation damping when a pile of the laminae is immersed in water. Motional impedance measurements with such a pile of annular nickel stampings show a high degree of resonance for radial vibration in air. Similar measurements in water confirm that the internal mechanical damping of the laminae is small compared with the radiation damping; the efficiency of conversion of electrical into mechanical energy is very good.

Various forms of these high-frequency oscillators have been constructed in accordance with the two principles mentioned above, but a detailed description would be out of place in the present article; enough to say that the three principal types are:

(i) The Scroll Type: longitudinal vibrations.
(ii) Ring Oscillators: radial vibrations.
(iii) Strip Oscillators: longitudinal vibrations.

In order to obtain sufficient "directionality" in the magnetostriction transmitter and receiver, the oscillators, particularly types (i) and (ii), must be mounted in some form of reflector. The sound-energy from a source of diameter large compared with a wave-length of the sound emitted is confined to a relatively narrow cone. This is an advantage from the point of view of economy of sound-energy; but in its practical application to echo-sounding a very sharply directional

transmitter and receiver may result in a loss of some of the echoes, particularly in a moving ship and over a rapidly shelving or undulating sea-bed. The choice of the angle of the beam is therefore a compromise.

The Receiver.—As already stated, magnetostriction receivers are identical in construction with transmitters. They are built up of the same thin nickel stampings wound with a few turns of low-resistance insulated wire and are mounted in similar air-filled reflectors to obtain the desired directional properties. Since both transmitter and receiver are highly directional, they may be mounted side by side in the bottom of a ship without risk of serious interference by direct sound. Both transmitter and receiver face the sea-bottom, and the receiver is consequently sensitive to high-frequency sound approaching from this direction only.

The Recorder.—Experiments have been made with various types of recorder, but the one giving most satisfactory results is that in which small electrical currents produce a stain on a chemically prepared paper. A large selection of chemicals is available for such a purpose, one of the best being a solution of potassium iodide and starch. The paper, soaked in this solution, is used in a slightly moist condition. The stain produced by the current has a brownish-purple colour which changes to a definite brown on drying.

The form of recorder preferred for short-range echo-detection is shown diagrammatically in Fig. 1. This recorder is driven from a small electric motor fitted with a governor to ensure constancy of speed. A pair of timing contacts are provided which may be used either as the actual transmitting contacts or as auxiliary contacts for the operation of a separate electromagnetic transmitting key. The recording stylus is carried on a traveller which engages with a helical groove cut in the surface of a cylinder geared to the main drive. Rotation of the cylinder produces a to-and-fro motion of the traveller across the paper. A simple cam in the traveller brings the recording stylus into contact with the paper in the left-to-right direction and lifts it off on the return journey. A roll of unsized paper is wound slowly past a wick, which wets it with chemical solution, or with water if the paper has been previously impregnated with chemicals. It then passes over a bevelled bar, where the record is made, and thence to a collecting spool. The instant of transmission of the sound-impulse is synchronized with the zero position of the stylus as it begins its traverse across the paper; at this instant a stain is produced on the record. While the high-frequency sound-impulse travels from the transmitter to the receiver via the sea-bed, the recording stylus traverses the paper strip. At the instant of arrival of the echo a second stain is produced on the paper strip. This procedure, repeated at regular intervals, results in two stained bands on the record, the first of which represents the instant of transmission and the second the instant of arrival of the echo. The distance apart of these bands is proportional to the depth of water through which the high-frequency sound has travelled. The scale of depth indicated by the

record depends, of course, on the speed of traverse of the stylus across the paper. For example, the width of the actual record in shallow-water sets is approximately 5 in. per 200 ft. of depth, since the stylus crosses the record in 1/12 sec. approximately. In a 200-fathom recorder the speed is one-sixth of this. A variable-speed drive might of course be incorporated to vary the speed of traverse of the stylus, so that the same paper-width would correspond to any required range of depth to be recorded. Provision is made in some recorders for a total range of depth of 0 to 420 fathoms. The recording stylus crosses the paper in a time corresponding to 70 fathoms, and by advancing the instant of transmission in steps equivalent to 50 fathoms the series of overlapping ranges 0–70, 50–120, 100–170, . . . 350–420 fathoms is obtained. This expedient increases the effective width of the record by 6 times. In another experimental recorder the initial depth-range, determined by the width of paper, is 0 to 240 fathoms with provision for a zero advance of 200 fathoms, giving a maximum recordable depth of 440 fathoms.

An additional commutator has been introduced which causes the recording stylus to make a series of dots on the paper at equal intervals of depth—every 10 or 20 ft. in the set for very shallow depths and every 10 or 20 fathoms in the deeper-water sets. The dots form a series of equidistant lines on the record and provide a very convenient scale for reading the depth. As the depth-scale is dependent for its accuracy on the speed of the stylus across the paper, it is important that this speed should be maintained constant. The driving motor is therefore provided with a reliable governor to control the speed within ½ per cent. A resonant steel-reed vibrator is mounted on the base of the recorder to indicate that the machine is running at the correct speed.

In some recorders designed specially for hydrographical surveying, provision is made for recording and numbering "fixes" to correlate the recorded depths with cross-bearings on shore-marks. At the instant of making a fix, a line is produced on the record by momentarily short-circuiting the depth-marking commutator. Each line is subsequently identified by a serial number printed near the edge of the record.

Conclusions.—The depth of the sea varies from 0 to 5,000 fathoms approximately, and the ideal depth-recorder might be expected to cover the whole of this range with the same percentage of accuracy at all depths. The majority of ships, however, have little or no interest in deep-water (oceanic) soundings but become more and more interested as the depth decreases. Ultimately, in very shallow water, a knowledge of the depth is of primary importance. A ship in very shallow or rapidly shoaling water, especially in insufficiently charted localities, must take frequent soundings. The importance of an echo depth-recorder therefore increases as the depth diminishes.

The depth range of the sea may conveniently be divided into three parts, (1) very shallow water, 0–30 fathoms, (2) water of medium depth, 30–200 fathoms, and (3) very deep (oceanic) water, 200–5,000

fathoms. Practically all ships which require soundings at all are concerned with the first of these ranges, 0–30 fathoms. Within this range the safety of the ship may be involved. Of less, but still very great, importance is the range of navigational soundings reaching down to 200 fathoms or so. Soundings in such depths are of value to the navigator who may use the record as a means of checking the position of the ship. Relatively few ships have any interest in depths beyond this range, say down as far as 5,000 fathoms.

The magnetostriction echo depth-recorder which has been described fulfils the more important requirements. It measures the depth, to about 1 ft., in water of any depth from zero to 30 fathoms or so and in this respect is valuable to ships in dangerous or unknown shallow waters. This sensitiveness to depth in shallow water reveals in considerable detail the presence of wrecks or large rocks on the sea-bed. There are also important applications in survey work in rivers and harbour mouths, where the recorder may be used to control dredging operations and to check the thoroughness with which such operations are carried out.* As regards navigation, experience has shown that the magnetostriction apparatus can give a good record of depth up to 400 fathoms or more, even when the sound is transmitted and received through a steel hull $\frac{3}{8}$ inch thick. The records were not appreciably affected by the noises made by the machinery and motion of the ship at the cruising speed of the vessels fitted. Good results were obtained in bad weather conditions, the rolling and pitching of the ship having but little effect on the record.

The magnetostriction system may also have any degree of "directionality" required. Hitherto it has been found satisfactory to use a conical beam of sound of semi-apical angle 20° or 30°. The comparative ease with which the receiver can be screened from the transmitter is due to the relatively short wave-length (about 4 in.) of the sound and to the directional properties of the conical reflectors.

Another advantage of the directional characteristic is that the soundings are taken directly, or almost directly, beneath the ship; little or no sound is transmitted sideways, and the receiver is therefore insensitive to echoes from submerged cliffs or banks. In this respect also the directional beam is more discriminative of detail than non-directional types and is less liable to miss a submerged rock or a wreck. It has been urged against the directional system that it is affected by the roll of the ship and by steeply sloping banks. Whilst it is true that some echoes may be missed under such conditions, the case is not so bad as it first appears. It must be remembered that the sea-bed is not a mirror, and that sound of short wave-length is returned to the receiver from directions other than the simple reflecting angle.

General Notes.—This completes an account of magnetostriction and the chemical recorder up to recent times, though already further advances have been made in design, especially in the increased size

* These and other special applications of Echo Sounding will be dealt with in Part III.

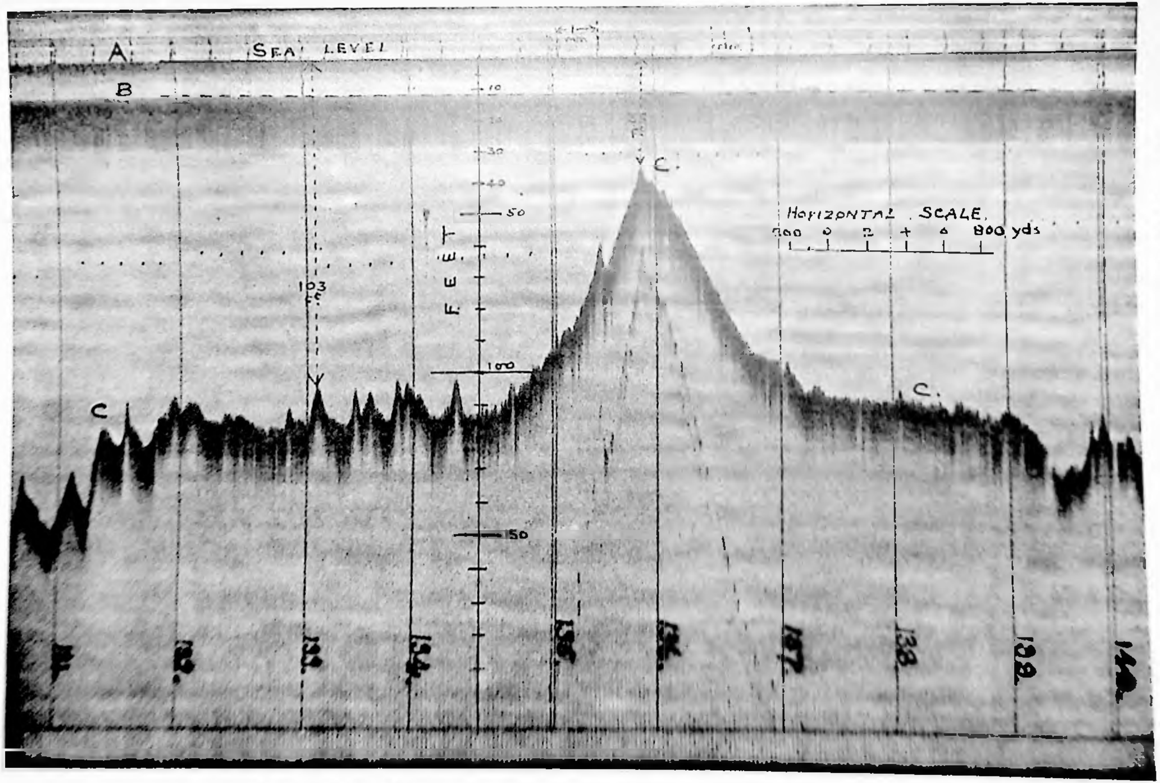


Fig. 2. Admiralty pattern Supersonic System: portion of a typical record.

of the vertical scale. For example, an echo-sounding set, recently made by Messrs. Henry Hughes & Son and giving every satisfaction, uses a vertical scale of $\frac{1}{4}$ inch of paper to 1 ft. of depth. These developments, however, will be dealt with in the final article, when it is hoped to show the several applications to which the latest sets can be put, as well as some of the curious and almost freakish phenomena that have been met with.

In the meantime it will be as well to remark a little more definitely on the great advantages of a recorder as compared with the sonic type of echo-sounder:

(1) *The Elimination of the Human Element.*—It has already been shown that soundings, *i.e.* the true echoes as received in the head-phones, are liable to confusion with a false echo or echoes, especially when the depth of water approximates the separation between transmitter and receiver (in the sonic or hammer type).

With the recorder there can be no mistakes; for these echoes are easily distinguishable from the true echo and can be discarded with a certainty that none except the very expert listener could guarantee in the sonic type.

(2) *Shallow and quickly changing depths.*—With a magnetostriction gear and a suitable recorder depths can be recorded to less than one foot below the position of the oscillator, and furthermore nothing, however small, can be missed. On one occasion the writer was able, not only to delineate the shape of a blockship lying on her side in the entrance to one of our harbours, but even to obtain an accurate sounding off the edge of her bilge keel!

(3) *Permanency of Record.*†—On the completion of any voyage the mariner has a complete record of all the dangerous and difficult bits of navigation which he has encountered during his trip, building up a storehouse of practical knowledge for the future.

Figure 2. Typical Record or Graph.—Fig. 2 represents a small portion of a record obtained by one of H.M. Surveying Ships when sounding in the vicinity of the Galloper Shoal during the ordinary course of her survey, and gives a vivid picture of the crossing of the Shoal. The top line A represents the surface of the water. The second line B shows the point of emission from the oscillator. The remaining line C shows an exaggerated picture of the sea-bed, the actual depth being measured from the top of A to the top of C. The short vertical lines above A represent minute markings, while the numbered vertical lines have been superimposed by the surveyor every time a "fix" is taken.

The vertical scale is represented by 5 inches of paper = 35 fathoms depth, *i.e.*, 1/42 inch of paper = 1 foot. The horizontal scale as shown by the minute marks with the ship steaming at

† This is not quite accurate, as at present the paper is still slightly sensitive to light, and after use must be kept away from daylight in order to prevent fading. Records, however, of 5 years and more of age are still in existence, and if kept away from light should last almost indefinitely. Experiments are already in hand to overcome this impermanency and will doubtless be successful in time.

6 knots, *i.e.* roughly 200 yards a minute, is also shown in the diagram. Presupposing 180 sound-impulses per minute, this means that an actual sounding is obtained approximately every 3 feet of the sea-bed!

Part III

The advance in echo-sounding methods has in the first two Parts been traced from infancy through the sonic stage to the supersonic, and finally to the combination of the latter with the recording element. Development on the whole has been rapid, and the time has now come when further major alterations are unlikely, and it is to the improvements of details that attention must be turned. To this end it is necessary to aim at standardization of types and parts, and it is for this purpose that the "Universal" recorder has been produced. Before entering on a description of this recorder it will be as well to recapitulate a little.

The transition from the hammer to the supersonic type has already been seen, together with the introduction of the first recorders, and it will be remembered that the actual visible mark or marks in the recorder were caused by the action of an electric current passing through and staining a paper impregnated with potasium iodide, the scale of the chart depending on the speed of the movement of the stylus or pen across the paper. Obviously in deep water the recording stylus is arranged to move at a slower rate, resulting in a smaller scale of depth to paper.

It was shown* that with the shallow-water set then in use the width of the paper was approximately 5 inches, representing 200 feet of depth, and the stylus took about one-twelfth of a second to traverse the record. Similarly, if the record represented 200 fathoms instead of feet, the time of traverse would be half a second instead of one-twelfth. Now, if a 5-inch record represents 200 feet of depth, one fathom would appear as 0·15 inch and one foot as 0·025 inch or roughly one-fortieth of an inch. For ordinary navigational purposes

* *Vide p.* 15.

and even for some hydrographic surveys this scale gave a sufficient degree of accuracy (about ± 1 foot), but the many demands for more precise work in connexion with harbour engineering, inland waterways, river bars, etc., proved the necessity for a larger scale. A larger scale meant an increased speed in the movement of the stylus, which in its present arrangement quite obviously must have a limit. The speed of the jerky reciprocating motion could not be extended much farther, though scales were actually increased to as much as ¼-inch to a fathom, the same stylus being used with slightly improved methods.

A drastic change was thus foreshadowed: the cylinder and its spiral drive had to go. A magnetic clutch was invented and made: its working was satisfactory for ordinary scales, but it was necessary to look ahead to the time when the demand became insistent for really large scales, and it was with this in mind that the first large-scale recorder was produced working on the "rotating-arm" principle. This was not a new idea but had been temporarily discarded in favour of the two systems previously mentioned, before the necessity for the very large scale had arisen.

Accordingly, there came into being a practical working recorder that could give a scale as large as one-eighth of an inch of paper to one foot of depth! On this scale the slightest alteration in depth is, of course, immediately visible and it is doubtful whether anything larger in the way of scales will ever be needed. This design, incorporating a rotating arm, has now been embodied in the "Universal" recorder, and one description of general principles will serve for both the "Universal" and the larger instrument already referred to above.

The "Rotating Arm Double Range" and the "Universal" Recorder.— The main principles differ but little from those of the magneto-striction system previously described and are very similar to the diagrammatic figure shown on *p.* 11 of Part II, with, of course, the exception of the stylus and its drive.

Engendered by the demand for a large open scale capable of delineating the shoalest depths, the problem of a recording instrument using a rotating arm to carry the recording stylus in lieu of the reciprocating mechanism became urgent. As described above, the higher speeds demanded by the pen rendered the reciprocating movement unsuitable.

The indication of a sounding obtained by an echo is inevitably a matter of very accurate timing, and so the element of the recording system must depend on a mechanism moving at a uniform speed and superimposing on that uniform speed the echo time of the sounding. It has already been shown that the scale to be used depends upon the pen speed, and when very large open scales are required this speed has to be of a very high order.

In the first instrument of the type an arm of 9-inch radius was used in order to give a high pen speed in traversing the paper, without running the instrument at an unduly large number of revolutions. Another consideration was that, by using a comparatively long

radius for the arm, the distortion or compression of the scale at each end due to the curvature was reduced to an unimportant percentage. Though this first type of rotating-arm recorder was, and still is, capable of a very high degree of accuracy combined with a large scale, it has the disadvantage of being cumbersome where space is a consideration; in order to overcome this disability the "Universal" recorder was evolved. In this instrument the radius of the rotating arm has been reduced to slightly under 4 inches, thus enabling the whole instrument to be contained in a case 11 inches wide, 16 inches high, and 11 inches deep.

The same system of electro-chemical recording is employed as before, but in this case, and in the larger instrument, the paper is supplied already moistened and is contained in a sealed tank inside the instrument. As before, the paper is drawn across the recording table at a uniform speed, having a definite proportion to the pen speed, and is then wound on a roll in the lower part of the instrument. The paper is 6 inches in width and the sounding scale occupies 5 inches of this space. A window, of some 8 inches in depth, in the front of the case gives a clear view of the record: the scale can either be engraved on the glass of the window or can be applied by a curved scale bar situated close under the track of the pen. The ordinary remote control for marking a "fix" by a momentary short circuit is fitted.

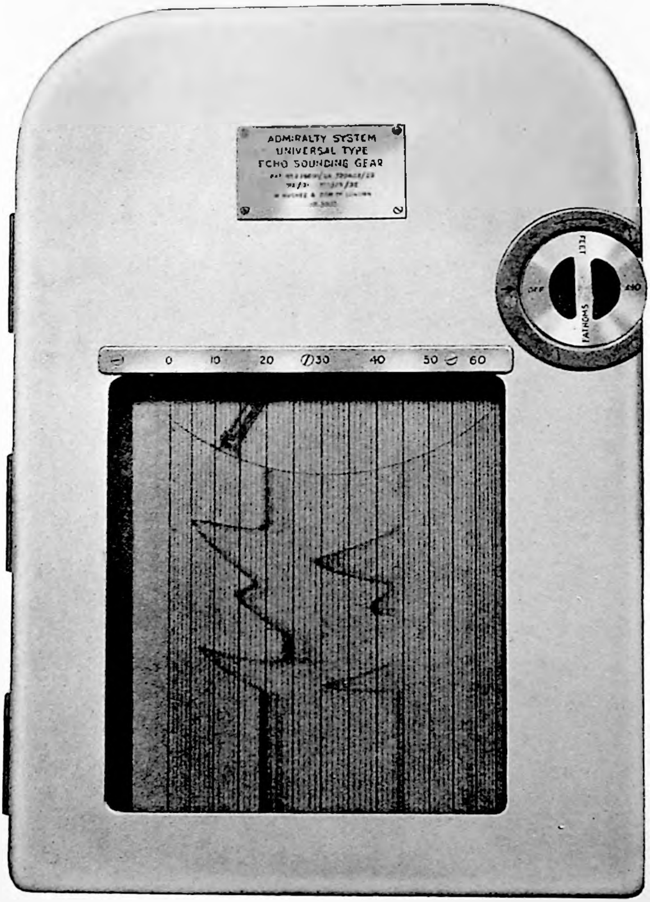
This instrument, although the same in appearance for all its various types, can be made up to suit any individual requirements in the way of scales: in its simplest form it is an instrument giving one scale only and has no change-speed gear and no phasing switch. The demands, however, of most surveyors have led to a type which has two speeds giving two scales, usually of the ratio 4 : 1, 6 : 1, or 10 : 1. For the British surveyor the 6 : 1 ratio is generally preferred, representing fathoms and feet, a simple lever changing from one to the other as necessary. The scale now adopted by British surveying ships is one giving 0 to 150 feet/fathoms, that is to say, representing one foot by 1 inch/30.

In addition, when desired, phasing switches admitting of increases in depth by steps of about 75 per cent. can be fitted; hence, in an instrument having a scale of 0 to 150 feet/fathoms, with a 75-per-cent. phase, soundings up to 450 feet/fathoms can be assured.

This instrument has the widest possible application and, though originally produced for ships or boats requiring a shallow open scale, it is equally suitable for deep-water scales up to 1,000 fathoms and, when fitted to a deep-water recording set, can be used up to 6,000 fathoms! Owing to its small size it can be conveniently placed on any bridge or wheelhouse in a position where it can readily be watched.

For use in surveying motor-boats a scale of 0 to 90 feet/fathoms has been adopted, though for special purposes the large scale of 0 to 40 feet is also supplied.

In this connexion attention is drawn to an admirable article



THE "UNIVERSAL" RECORDER

This illustration and the graphs on Plates XIX and XX are reproduced by kind permission of Messrs. Henry Hughes & Son, Ltd.

written in the international *Hydrographic Review* of May 1935, entitled "Sand Waves in the North Sea" by Joh. van Veen, Chief Engineer of the Netherlands Waterways. The whole of the work and all his delightful accompanying records have been obtained with one of the instruments of this type manufactured by Messrs. Henry Hughes & Son, Ltd., 59 Fenchurch Street, London.

This now completes the general description of the various British Admiralty Pattern Echo-sounding Instruments of the supersonic and recording type. An illustration of the latest "Universal" recorder is given in Plate No. XVIII. The glass window and the end of the rotating arm carrying the stylus are clearly visible, as also the actuating switch in the top right-hand corner for changing the scale from fathoms to feet.

Progress on similar lines has, of course, been made by other countries also, and notably by Messrs. Marconi, but it is outside the purpose of this article to enter into any description of the systems of other countries. At the moment, as far as the writer's experience goes, and in the opinion of many foreign experts, the British Admiralty type is far ahead of any other echo-gear at present in existence: I think it is safe to say that there is not another machine extant capable of giving accurate results on the large scale described above of one-eighth of an inch to a foot.

Freaks and Phenomena.—It does not need much imagination to realize that this rapid development of large-scale recording must occasionally lead to some rather unforeseen results, sometimes giving the Navigator furiously to think. Even before the days of the recorder the old pattern sonic gear produced some astonishing echoes when operated by a really well-trained observer.

On one occasion one of H.M. Surveying Ships was about to anchor in deep water, about 20 fathoms. Shortly before the anchorage was reached, "shallow water 6 fathoms!" was called by the observer. Of course at this sudden shoal the engines were put full speed astern, when 20 fathoms was again reported. When the ship proceeded ahead once more, the phenomenon occurred again—twice! again—thrice! It was only then that the Commanding Officer realized that in adopting the usual seamanlike precaution of veering his anchor and a shackle of cable (12½ fathoms) to obviate any chance of breaking the anchor on a hard bottom, he had inadvertently brought it into the range of his echo-sounder. Being largely non-directional, soundings were being obtained merrily and rapidly off the anchor itself in about 6 fathoms! On going astern, with the anchor and cable falling back to a vertical position, correct soundings were once more heard in 20 fathoms.

With the introduction of the recorder and the more directional beam this contretemps was avoided, but many temporary "shoals" have been "discovered" in the neighbourhood of Light Vessels, eventually to be revealed as echoes picked up in passing over their moorings.

Another form of shoal which has been met with of late is, to make

a bad joke, a "fishy" one, or in other words, a shoal of fish! Although this is apt to make things rather trying for the Surveyor and Navigator, it opens up large fields for research work by the Fisheries Departments as well as for the location of herring, cod, etc., by the fisherman. This will be referred to amongst the illustrations later.

One last description of a "fishy" shoal is extracted from the May 1935 number of the I.H.B. *Review*, by whose kind permission this is reprinted, being taken from an article published by the Hydrographer of the Navy, Rear-Admiral J. A. Edgell, O.B.E., R.N.

The following is an extract (from the Report of H.M.S. *Challenger*).

"In April 1933 whilst steaming down the Channel in the vicinity of Start Point, soundings were being obtained of about 40 fathoms with the Deep-Sea Echo Gear; the bottom was of an even depth, when a report was received that the soundings were shoaling rapidly and almost at once 5 fathoms were recorded. The engines were put astern, and when the wash subsided soundings of about 40 fathoms were obtained; these were checked by lead.

"A buoy was dropped and the ship steamed slowly round in the vicinity; on going ahead again the same thing occurred, soundings shoaling suddenly from 40 to 5 fathoms when, on the engines being put astern, 40 fathoms was again recorded and instantly tested by lead. This continued for some time, the phenomenon being observed whenever the ship went slowly ahead and then astern, until finally, although covering precisely the same ground near the buoy, continuous soundings of about 40 fathoms were obtained over an even bottom.

"The conclusion arrived at was that echoes were being obtained off a dense shoal of fish* swimming at a depth of about 30 feet, these collecting under her bottom when the ship was going slowly ahead, but scattering whenever the engines were put astern."

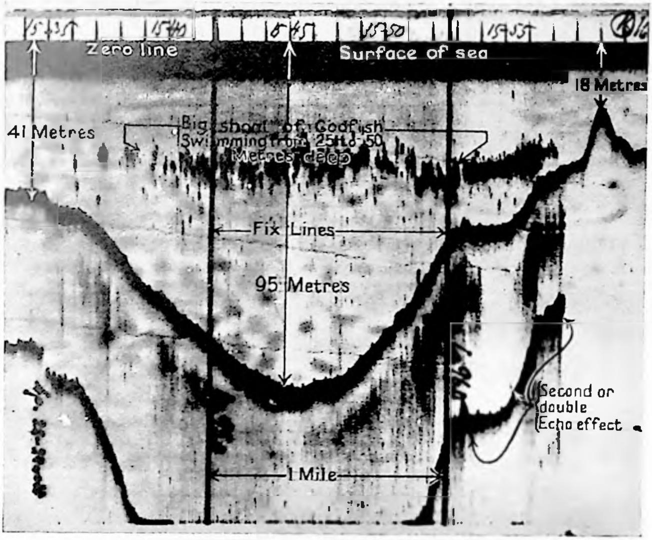
The record was very clear and Admiral Edgell ends up his remarks by saying:

"There appears no doubt at all that this phenomenon was produced as suggested by *Challenger*, by a dense shoal of fish swimming underneath the ship's bottom and dispersing when the action of the propeller going astern was felt.

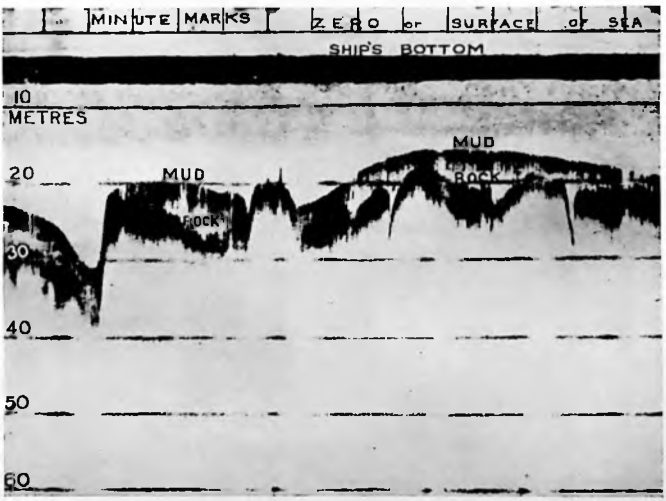
"Incidentally, it is worthy of note that the echo still showed a depth of 40 fathoms *through* the layer of fish!"

Plate No. XIX shows a good example of the value of echo-sounding to the fishing fleet. The record which was obtained near the Lofoten Islands shows a "deep" of about 95 metres, while in the middle of this great valley can be clearly seen an enormous concentration of cod, a mile and a half long, swimming from 25 to 50 metres below the surface. A W/T call to the fishing fleet, and the result—a record catch. It is of special interest as this record was obtained by the Norwegian trawler *Johan Hjort*, which is actually one of the Norwegian Fishery Research Ships, fitted with a British Admiralty Pattern Magnetostriction Recording Gear.

* Obviously seeking shade from a bright sun.



GRAPH SHOWING SHOAL OF COD



GRAPH SHOWING MUD AND ROCK

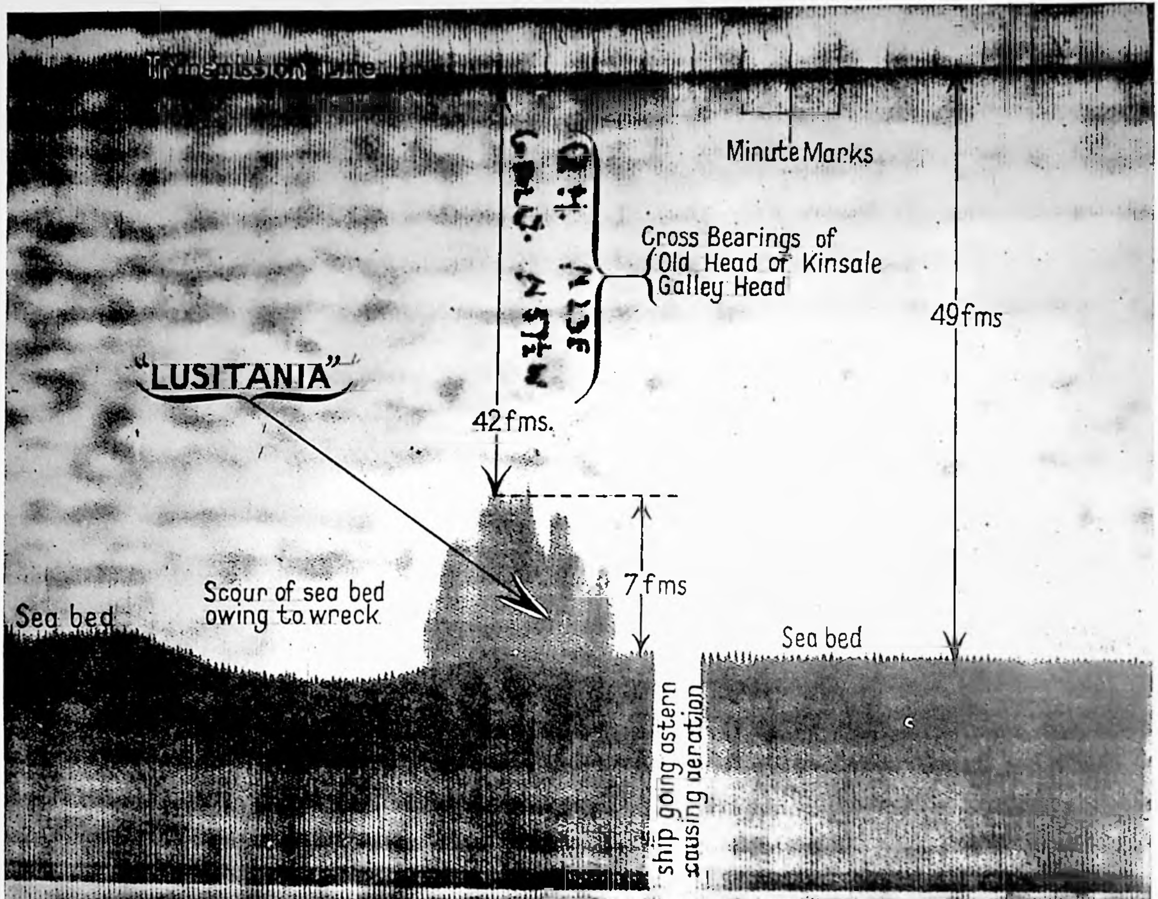

Minute Marks
Cross Bearings of
Old Head of Kinsale
Galley Head
49 fms
"LUSITANIA"
42 fms.
7 fms
Scour of sea bed
owing to wreck
Sea bed
Sea bed
ship going astern
causing aeration

Plate XX

The reproduction is largely self-explanatory, but perhaps a word about the "second" or "double" echo might be interpolated to advantage. This phenomenon frequently happens when overmuch power is being used, with the result that the radiated energy, not content with obtaining one echo, goes down and up a second time and sometimes even a third, and in theory *ad infinitum.* The second and third echo are very often seen and easily detected and discarded, since, although the contour is reproduced in exactly the same way as from the original echo, all heights and depths are necessarily doubled or trebled.

Many records and reports of fish discovered by this means are being received from all directions, and though the recorder is not yet able to *name* every fish it comes across, it is often possible to distinguish between species such as cod, herring, and, say, the very small fish such as brisling. For fishery research work an instrument of this type is, of course, a necessity nowadays.

Wrecks.—Turning to yet another side of echo recording: Among many successful searches for wrecks there is a record obtained by one of H.M. Surveying Ships near the mouth of the Thames Estuary during the course of her ordinary surveying operations. Again the record was self-explanatory and the picture of the wreck is remarkably clear; there is a gap in the sounding due to aeration of the water and formation of bubbles on the ship going astern. This photograph, accompanied by a letter from the Hydrographer of the Navy, was published in *The Times* of 28th September, 1934.

To the lay mind anyhow probably the most interesting of all the illustrations is Plate No. XX exhibiting the accurate and romantic representation of a wreck which, after considering all the evidence, is almost certain to be the ill-fated R.M.S. *Lusitania.* The soundings shown in this record are obtained in the "second phase" (25 to 60 fathoms), that is to say, the transmission line starts at +25 fathoms. In this case this addition has already been applied to the depths shown, *i.e.* 25+17 fathoms = 42 fathoms. This is only mentioned lest some keen reader should question the apparent discrepancy between the lengths of the lines representing 42 and 7 fathoms respectively!

The position of the wreck is clear and the scour of the sea-bed is well marked and similar to that seen in *The Times* illustration. The cross-bearings will be noticed hastily scribbled on the record with an "electric pencil": the position of the ship when going astern after passing over the wreck is marked by the absence of soundings owing to the aeration of the water. Incidentally, I may add that nearly 7 million soundings were obtained in 30 days and 2,000 square miles were closely examined.

Engineering Possibilities.—To register on the surface of soft mud and to divine what lies beneath it; to study the bottom of the sea and to watch the formation of sand-ripples; to examine and determine the problems of silt, the effects of tides and currents, the shifting of shoals, waterways, and bars: these are all part of the recorder's daily duties.

Plate No. XIX shows how the rock formation can be clearly seen below the surface of the mud: *i.e.* the beam from the oscillator has registered first on the soft mud surface, passed through and been reflected again by the hard rock bottom. What a boon to engineers seeking a new harbour! A picture showing where to dredge, where to bore, and where to lay the foundations of future piers and docks laid before the eye! Many better records of this type have been received but this is the only one available at the moment; it will serve to show the unlimited possibilities that are opened out.

The fact that it has succeeded in portraying sand-ripples and their formation gives a good idea of the possibilities of a large-scale recording instrument. Here, on the full scale, a metre is represented by approximately $\frac{3}{4}$-inch of paper, and the little sand-ripples are easily distinguished and can eventually be drawn to scale showing the exact contour of their formation.

Finis.—And so, though these articles are now finished, the possibilities of modern scientific development are unending. The stratosphere has been explored—14 miles above the earth's surface; the deepest depths have been "echoed"—5,703 fathoms; and now we are vain enough to make pictures of something we cannot see.

We portray sections of the sea-bed, prying into under-sea life, interrupted sometimes by shoals of its denizens, but always looking farther and farther in search of the truth.

"Echo" is not trying to make a world fit for heroes to live in but, rather, safe for ships to pass on the seas upon their lawful occasions.

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